New Literature: Ph.D. Thesis

Life Cycle Inventory Analysis for Decision-Making
Scope-Dependent Inventory System Models and Context-Specific Joint Product Allocation

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In this thesis, Life Cycle Inventory Analysis (LCI) is structured in view of its use in decision-making. Emphasis is put on often encountered inconsistencies, namely the set-up of LCI system models, the representation of decisions and value choices of actors (e.g., firms) involved in a product system, and the representation of changes within the economic system.

An LCI system model consists of numerous individual processes. Their relations are identified according to economic (such as market information or contracts) instead of mere physical information. Based on such a system model, LCA provides environmental information consistently complementary to private cost statements.

A disutility function is introduced, which is used for the default choice of (marginal) technologies or technology mixes within the product system, and for joint product allocation. The disutility function adds up economic information (i.e., private costs) and environmental information to total "social" costs. For that purpose, an environmental exchange rate is introduced. The exchange rate mirrors the variable influence of environmental aspects on decisions in different political entities such as nations. It may also express differences in uncertainty perception of the actors directly and indirectly involved in the production of the good or service under analysis.

To reflect the consequences of decisions, models capable of representing changes within the economic system shall consist of processes represented by marginal technologies, the technologies put in or out of operation next. The disutility function is used for the identification of the marginal technologies throughout the whole product system. System models are classified according to the distinction of planning tasks in firms, i.e., short-, long- and very long-term decisions. It is assumed that all firms connected within the process network of a product make their decisions based on the same time horizon (i.e., short-, long-, and very long-term). Aspects of non-linearity occur in the case of short-term optimisation. Semi-dynamic modelling in the case of very long-term planning shows its limited added value compared to static modelling.

Short-term decisions comprise the optimisation of existing production facilities. That is why capital equipment is not included in the Short Run system model. In the case of long-term decisions, capital equipment is included in the Long Run system model depending on the status of the market situation of the product under analysis. In shrinking markets, where no replacement investments are made, capital equipment is left out whereas in expanding and saturated markets it is included. Very long-term decisions require consistent scenario about the future status of society, economy and the environment. For the support of very long-term decisions with the help of LCA, emphasis is put on the accuracy of the representation of the future status, and much less on the detailed modelling of the transition period towards that future status.

The disutility function is applied in joint product allocation assuming that environmental aspects influence decisions of a firm and its clients. Joint production situations are discriminated according to the decision context, i.e., the number of decision-makers involved, and according to the market for which joint products are manufactured.

In a single decision-maker situation within sufficiently working markets, allocation factors are chosen in view of the competitiveness of the joint products. The competitiveness of two or more joint products is determined using multiobjective optimisation.

In a single decision-maker situation within monopolistic markets, the price-output relation is determined in view of maximising profits by means of constrained optimisation.

In a multiple decision-maker situation, several parties negotiate for a voluntary coalition. The aim is to evaluate an allocation key satisfactory for all parties. A game theoretic approach is used to model such situations.

The cases "national electricity mix" and "small scale gas-fired combined heat and power generation" illustrate the new methodological approaches. The Eco-indicator 95 impact assessment method is adapted to recent knowledge about environmental damages. In particular, characterisation factors for the emission of radionuclides in air, fresh and sea water are presented. They are fully compatible with the present Eco-indicator impact assessment method. The adapted Eco-indicator is used for the environmental assessment of the various electricity and heat generating technologies used in the case studies.

The environmental performance of the Swiss national electricity mix represented by an economically- and a physically-based model is determined. The differences in terms of single environmental impacts are significant but minor in terms of "social" costs. The determination of marginal power plants is sensitive in respect to the underlying forecast of electricity consumption. In a system model where an increase in electricity demand is prognosticated, electricity shows a relatively good environmental performance which promotes electricity applications. But also the opposite assumption, a future decrease in electricity consumption, leads to a consistent outcome. A comparison of our results with a forecast made for the European electricity supply industry confirms the accuracy of the disutility function to a considerable extent.

Context-specific allocation in combined heat and power (CHP) production is compared with traditional allocation approaches such as the "avoided burden"-approach or allocation based on economic or arbitrary physical criteria. The competitiveness of the CHP plant highly depends on the damage cost scenario for global warming. In terms of "social" costs the CHP plant is competitive compared to combinations of existing fossil-fueled power plants and natural gas-fired boilers but also compared to nuclear power and gas-fired boilers (low CO_2-damage costs scenario). Gas-fired gas combined cycle power plants show a similar performance like the CHP plant if combined with natural gas-fired boilers. However, the uncertainties in the data qualify the generalization of the conclusions from both case studies.

It is concluded, that the guiding principle formulated in this thesis, namely that LCA shall complement economic information, leads to a consistent and feasible methodology capable of representing changes within the economic system.

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